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EXPERIMENTAL EVALUATION OF CLOSED LOOP PULSATING HEAT PIPE WITH WATER BASED WORKING FLUIDS

N. SANTHI SREE[1*], Dr. N. V. VS. SUDHEER[2] & Dr. P. BHRAMARA[3]

[1]*Research Scholar, Department of Mechanical Engineering, Acharya Nagarjuna University, Guntur, Andhra Pradesh, India*

[2]*Associate Professor Department of Mechanical Engineering, RVRJC College of Engineering, Andhra Pradesh, India*

[3]*Professor, Department of Mechanical Engineering, JNTUH, Hyderabad, India*

ABSTRACT

In this paper, thermal performance of closed-loop pulsating heat pipe was experimentally analysed. PHP consists of three different sections namely evaporator, adiabatic and condenser. For experimentation copper tube having 2.0 and 3.6 inner and outer diameter respectively was considered. Water, Ethanol, Methanol, Acetone and binary mixtures are selected as working fluids. 50%, filling ratio is considered. Copper tube bent into 8 turns with 16 parallel channels is considered for experimentation. Heat inputs ranging from 20 to 100 W was supplied depending upon the operating range of fluids. Experiments are conducted by placing PHP at vertical bottom heat mode. For a better understanding of PHP experimental study is considered as one of the important influencing parameter i. e. working fluid. At different heat inputs, Characteristics of the average evaporator temperature and thermal resistance were analysed. The results shows that with increase of heat input thermal resistance decreases more rapidly. In comparison with the other working fluids, acetone gives best performance. Among binary and pure working fluids binary shows good performance. Water, acetone, binary mixture exhibits better heat transfer performance characteristics compared to other binary mixtures. Among all the orientations vertical bottom mode position gives the least thermal resistance values compared to other positions of PHP.

KEYWORDS: Binary Mixtures, CLPHP, Pure Fluids, Thermal Resistance & Working Fluids

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Original Article

1. INTRODUCTION

To transport thermal energy, conventional heat pipes are the most common effective procedure. For the enhancement of thermal management of a variety of applications such as electronic cooling, space applications, heat exchangers and economizer's heat pipes are the best solution. Pulsating heat pipes are one of the remarkable result of these challenges among different types of heat pipes. Akachi proposed and patented Pulsating heat pipes in the 1990s [1]. Experimental investigation were carried on two phase system which were closed. The total device is divided into three parts namely evaporator, adiabatic and condenser section. Condenser section is placed on top portion whereas evaporator section is placed in bottom portion so that due to gravity the liquid may go downwards. Working principle of PHP is based on the phase change phenomena in a capillary tube and the principle of oscillation for the working fluid. The following figure describes working principle of closed loop pulsating pipe with three sections indicating the flow with liquid slugs and vapour bubbles.

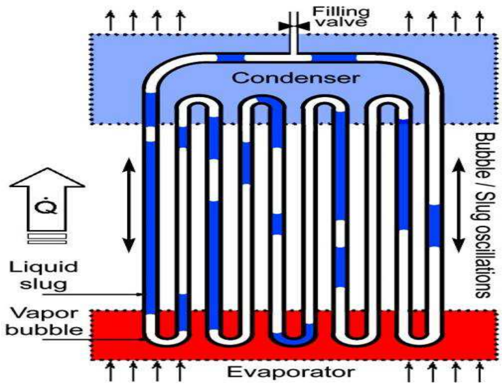

Figure 1: Schematic Representation of CLPHP [7]

The phenomena of phase change and thermodynamic behaviour of PHP is mainly depending upon its performance parameters like working fluid, heat input, no of turns, orientation of PHP, and also filling ratio. Pulsating heat pipes are generally made of small internal diameter. To exist, liquid and vapour slug's diameter of the tube should be small enough. Before applying any thermal load inside the pipe the working fluid is partially filled and sealed under vacuum. This elevates working fluid capillary action upon heat supply from the region of the evaporator. Due to the pulsating flow of liquid –vapour the heat will be transferred to the condenser region. This promotes capillary action of working fluid upon supply of heat from the evaporator region. The supplied heat is transferred to the condenser region via the pulsating flow of liquid-vapour within the closed channel of the pipe. The heat is transferred to the condenser through the combination of vaporization and sensible heat flow via bubble/slug/annular flow.

2. LITERATURE REVIEW

In recent years to understand heat transfer performance with different working fluids of Php various investigations have been done. Akachi patented PHP [1]. Mameli et al., [2] conducted experiments on PHP thermal performance working with water (4.5%wt) and ethanol (95.5%), Azeotropic mixture, in comparison with pure ethanol. In term, as of overall thermal resistance, no measurable difference was observed. Dadong and Cui [3] indicate that for the same filling ratio with the increase of heat input, thermal resistance decreases for all the fluids. At higher heat inputs thermal resistance decreases more slowly. From large to small, thermal resistance varies in the order of water, ethanol, methanol and acetone. Kammuang-lue et. al [4] suggested that, for the higher latent heat of the working fluid, higher will be the heat flux. Meena et al. [5] concluded that critical heat flux varies with the latent heat of vaporization. Working fluid with high critical heat flux has lower latent heat of vaporization values. Charoensawan et al. [6] concluded from a series of experiments that the capability of heat transfer mainly depends on the evaporation/condensation lengths, the number of turns, inner diameter, and working fluids. With increasing heat input there is a smooth decrease in thermal resistance. Khandhekhar et al., [7] had observed that the PHP with 2 mm diameter was found to be better than that of 1 mm diameter because the thermal resistance of 2 mm inner diameter PHP is less compared to 1mm diameter tubes. He experimented with40 turns with two different diameters PHP. Corresponding experimental results when compared to the 2 mm diameter tube, PHP1 mm inner diameter PHP achieves very high axial and radial heat flux values. The performance is strongly dependent on the flow pattern existing inside the tubes. Tong et al [8] recorded flow visualization during start-up period; and at steady state the working fluid circulates. Once circulation has attained the direction of circulation is consistent. Pachagore et al. [9] studied that in case of copper tube, the pipe wall heat transfer is by conduction and in PHP it is by convection. Shafii et al. [10] concluded the 95 % is due to sensible heat only, latent heat serves only to drive the

oscillating flow. Wang et al. [11] conducted experiments at different diameters of PHP with R141b, water and ethanol and concluded that water is best fluid due its wide operating range and its heat transfer rate is also very high. Han et al.'s [12] experimentally investigated the effects of working fluid, physical properties on PHP flow and heat transfer. The study emphasizes the role of viscosity and phase change parameters on the PHP heat transfer performance.

3. EXPERIMENTAL SETUP

In this experimentation closed loop pulsating heat pipe (CLPHP) is considered for investigation. The CLPHP consists of an evaporator, adiabatic, condenser sections with 42 mm, 170 mm, and 52 mm respectively. Borosilicate glass is placed at a length of 100 mm in adiabatic section to visualise the pulsation motion of PHP. To avoid heat loss, a thick layer of insulating material was wrapped around the evaporator block. The tube length 264 mm was folded in such a way to obtain 16 parallel channels and 8 U tube bends closed end to end to make a closed circuit using T-joints. To create vacuum inside PHP a reciprocating vacuum pump was connected to the filling valve. A pressure transducer is located /provided at the condenser section for pressure readings. The data acquisition system is provided with a temperature scanner to record the temperature readings. DAQ is equipped with Thermocouples in order to generate temperature data from the PHP. Heat input to the evaporator was controlled through a control panel which consists of digital voltmeter and ammeter. The figure shows the schematic diagram of PHP.

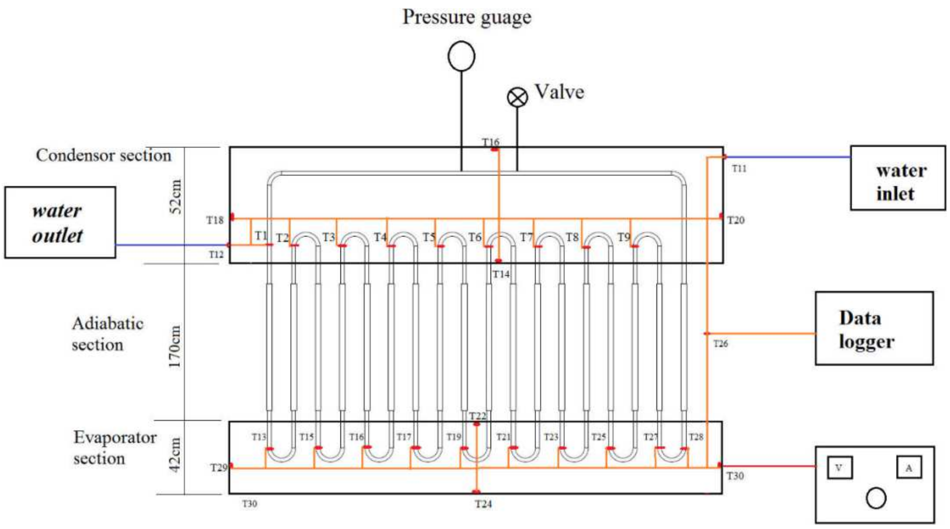

Figure 2: Schematic Representation of CLPHP

4. RESULTS AND DISCUSSIONS

According to the following procedure the heat transfer performance CLPHP working with both pure and its binary mixtures as working fluids were obtained.

- Heat input was given at Evaporator section and is stepwise increased uniformly until the system reaches a stable condition.
- Corresponding to each heat input the temperatures of thermocouples at the evaporator, condenser were recorded using the data logger system. The average temperatures of evaporator and condenser were determined.
- By using the formula (1) thermal resistance of CLPHP could be determined.

$$Rth = \frac{(Te-Tc)}{Q} \quad (1)$$

Where Q= heat input,

$(Te - Tc)$ =Difference between evaporative and condenser average temperature.

Rth =Thermal resistance.

4.1 Effect of PHP with Pure Working Fluids

The working fluid behaviour is mainly dependent on the thermo physical properties [21]. From the results of research work so far conducted it is clear that the working fluid should satisfy the following features: high latent heat, low surface tension, a higher value of (dp/dT) sat, high specific heat and lower dynamic viscosity value. Among all the properties latent heat of vaporization is the main property which affects the slug and plugs of the motion of liquid in a tube and also heat transfer. From the table, it was observed that latent heat and boiling points are more for water compared to acetone, ethanol and methanol. Therefore, at low heat inputs, hardly water can boil. Water has more ability to carry the energy and also it has a strong ability to resist drying out. At initial periods for large dynamic viscosity and surface tension values, thermal oscillation of water is very hard. Because of this the temperature at the condenser section of PHP is low and the temperature at evaporator section is high, and corresponding thermal resistances is also high at initial periods. With relatively lower dynamic viscosities values of methanol and acetone leads to small motion resistance, while a large value of (dp/dT) sat leads to finer pulsation. The lower values of latent heat of vaporization, low boiling point, and liquid specific heat acetone is most widely used for easy start up.

For working fluids (pure and binary), as heat input increases step wise thermal resistance decreases smoothly. At lower values of heat input, PHP unable to attain stable behaviour. The circulation of fluid is also not started. Initially chaotic motion of the fluid was attained. Wall friction of fluid is negligible due to liquid viscosity. The evaporator temperature increases as the heat input value increases. The adjacent tubes would be hot and cold alternatively. For a given experiment the circulation of liquid may take arbitrary direction at the range of heat input 30 to 80 watts (CLPHP works good for all different working fluids). After this the working fluid boiling point the dry-out behaviour conditions are depended.

The following figure shows thermal resistance variation with heat input for pure fluids.

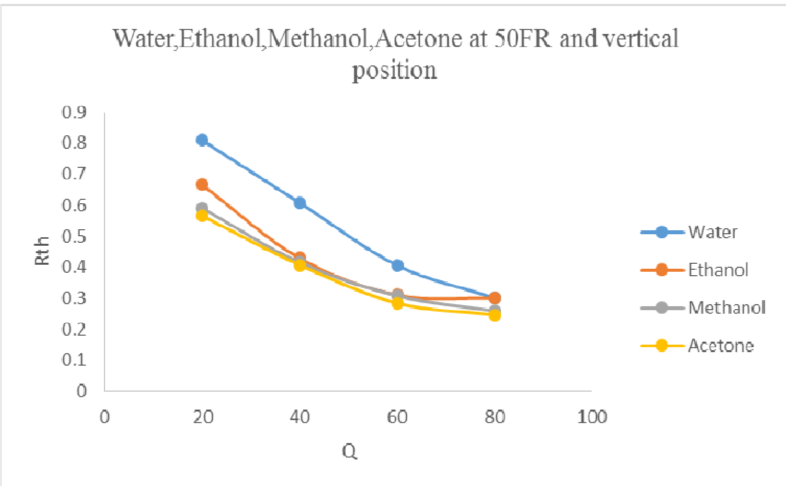

Figure 3: Variation of Thermal Resistance (Rth) vs Heat Input (Q) of PHP with Pure Fluids

4.2 Effect of PHP with Binary Mixtures

4.2.1 PHP with Water-Acetone as Working Fluid

The thermophysical properties of Water and acetone are different from each other. The (dp/dT) sat of acetone is three times more than that of water at atmospheric conditions. But latent heat of vaporization is 4 times more than water. By considering all the properties of water-acetone mixture water has strong combination with acetone in PHP's.

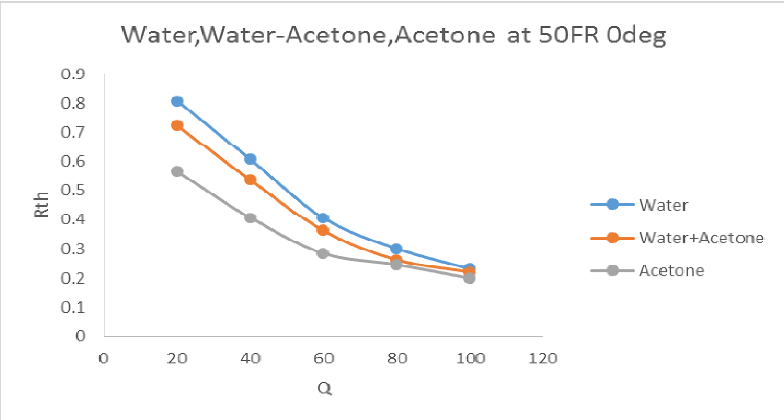

Figure 4: Variation of Rth vs Q with Water based Acetone with Pure Water, Acetone

In Figure, pure acetone always shows better thermal performance when compared with water and water-acetone binary mixture as a working fluid. Under large heating power, acetone is easy to dry-out. With the addition high specific heat and high latent heat of fluids to acetone, the CLPHP can improve its heat transfer performance. Anti-dry out situations also can be improved by adding water to the acetone. At high fill ratios, pure working fluids will have lower thermal resistance than that water-acetone mixtures. At high heat inputs, all binary and pure working fluids are almost stable. There is no considerable circulation of fluid initially at lower heat input values. This causes variations in thermal resistance values of pure fluids.

4.2.2 PHP with Water-Methanol as working Fluid

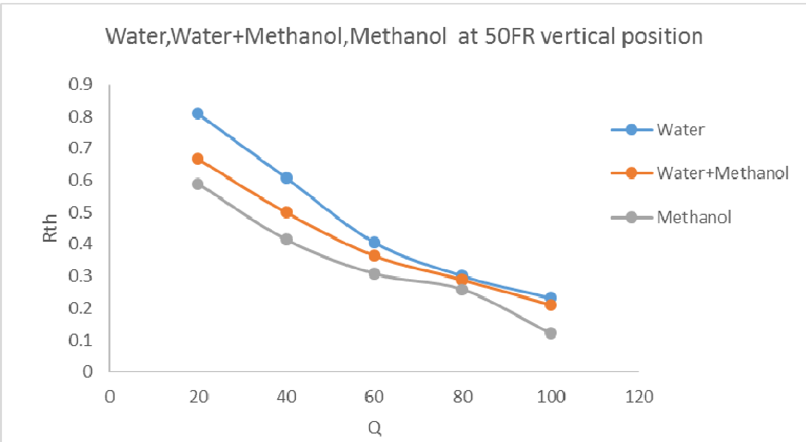

Figure 5: Variation of Rth vs Q with Water based Methanol with Pure Water, Methanol

Whereas in Figure, CLPHP operating with Water-methanol binary mixture as working fluid gives better performance when compared to water and pure methanol. Drastic variation in thermal resistance value was observed at initial heat input values for pure working fluids. At higher heat input values dry-out phenomena observed for the water-methanol binary mixture.

4.2.3 PHP with Water-Ethanol as Working Fluid

Pure Ethanol gives better performance than water and water-ethanol binary mixture as working fluids at moderate heat input values. At higher heat values binary mixture shows better performance. Water–ethanol has a maximum phase range and moderate boiling point. The ethanol in the vapour phase is greater than that of water in the vapour phase when phase change phenomena of mixture occurs. Other way water content in the liquid phase is higher than ethanol in the liquid phase.

The Water-ethanol mixture shows excellent heat performance value at a value of 60 W heat input. When the change of phase occurs conversion of ethanol liquid to vapour takes in quick time compared to that of water. At the same temperature levels, vapour pressure of water is greater than saturation pressure. In the liquid phase conversion water transfers more quickly than ethanol. This results in relatively smaller values of thermal resistance for water-ethanol mixture after 40 watts of heat input. At lower fill ratios water-ethanol mixture performs better than pure water and pure ethanol fluids.

From Figure it is inferred that pure water is having more thermal resistance variation than any water based binary mixture among all the working fluids, and pure acetone is having least thermal resistance variation among all the working fluids which are used in the present CLPHP experimentation. This is due to the difference in the thermophysical properties of the working fluids. Therefore it can be concluded that from the experimental analysis pure acetone exhibits the best thermal performance in comparison with other binary and pure working fluids that are used. It was observed that dry out occurred at an algebraic mean value of boiling point of binary mixtures.

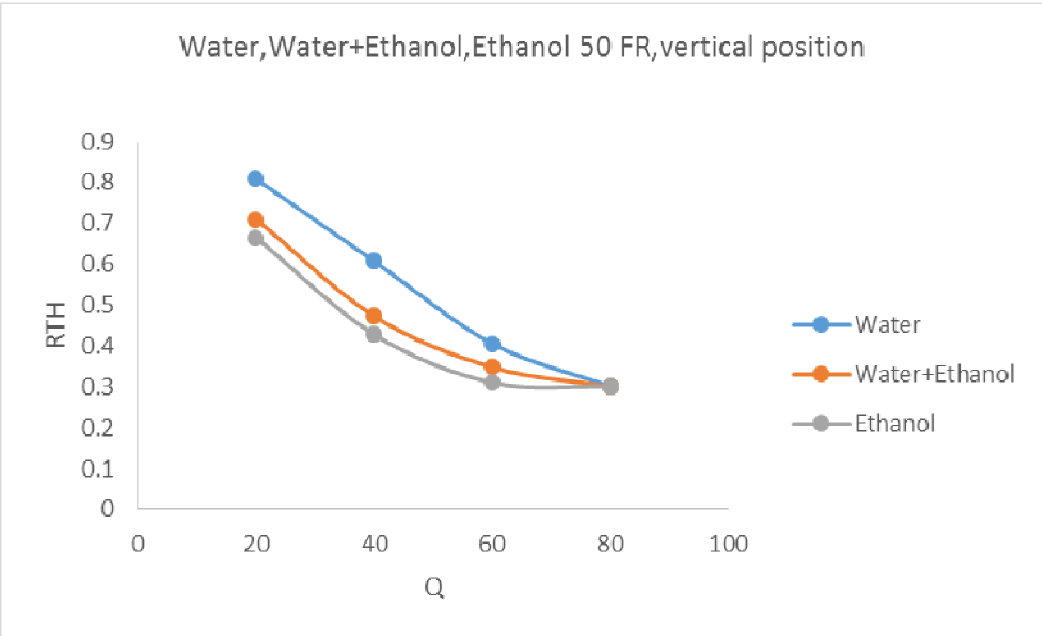

Figure 6: Variation of Rth vs Q with Water based Methanol with Pure Water, Methanol

Among all the binary mixtures Water-ethanol, Water-Methanol and Water-Acetone, the PHP filled with Water-acetone mixture showed the best heat transfer performance value. The following graph describes the same. At 80 W water-ethanol exhibits a thermal resistance of 0.3009°C/W, water-methanol exhibits a value of 0.289061°C/W whereas water-acetone exhibits 0.2624°C/W.

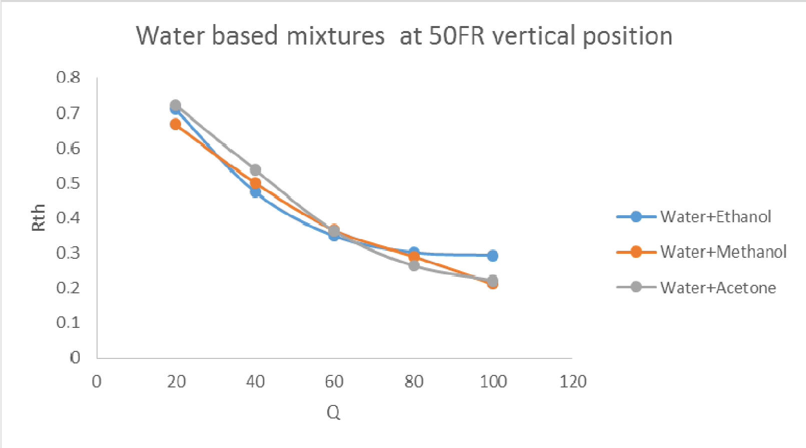

Figure 7: Variation of Rth vs Q with Water based Mixtures

5 CONCLUSIONS

To study the effect of working fluid on the thermal performance of CLPHP, pure and binary mixture fluids have been considered. An experimental analysis has been carried out on 8 turn PHP with capillary dimensions. For experimentation, various working fluids have been chosen depending upon their operating conditions, thermo physical properties and thermo mechanical boundary conditions.

The following conclusions have been withdrawn from the study:

- The evaporator temperature of all fluids increases as the heat input value increases.
- At high heat inputs, methanol shows lower average evaporator temperature.
- With an increase in heat input value the variation of thermal resistance decreased for all pure and binary mixture working fluids.
- At heat input of 90W, 85W, 80W dry-out phenomena were observed for Water- Ethanol, water-Methanol and Water-Acetone binary mixtures respectively.
- Among binary mixtures, Water-methanol gives a better thermal performance.
- Water shows the highest values of thermal resistance variation compared to other pure fluids.
- From large to small, the variation of thermal resistance among pure fluids is water, ethanol, methanol, and acetone.
- To start pulsation in the PHP pressure distribution is very important.
- At higher heat inputs gravity plays an important role in heat transfer of PHP.
- PHP successfully performs at a vertical bottom heated position and gives better performance.
- Whereas in binary mixtures the variation sequence from large to small is Water-ethanol, water-acetone and water-methanol.
- For an 8 turn CLPHP, among all the pure and binary mixtures pure acetone gives a best thermal performance.

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AUTHORS PROFILE

N Santhi Sree, Completed B.Tech in Mechanical Engineering from Koneru Lakshmaiah College of engineering and M.tech in Thermal Engineering from JNTU, Hyderabad, pursuing Ph.D from Nagarjuna University, Guntur, Andhra Pradesh. Member in SAE. Published paper on Thermal Analysis of closed loop Pulsating heat pipe at IJMPERD, April-2018.

Dr. N.V.V.S Sudheer, Working as Associate professor, in the Department of Mechanical Engineering at RVR&JC College of engineering, Guntur. His educational qualifications include Ph.D from Osmania University. M.Tech. in Heat Power from JNTU, Anantapur and B.Tech. in Mechanical Engineering from ANU

Dr. Panitapu Bhramara, Working as Professor in department of Mechanical Engineering at JNTUH College of Engineering Hyderabad Kukatpally Hyderabad - 500085. She completed he Ph.D in Refrigeration and Air conditioning.